

## TITLE OF THE INVENTION

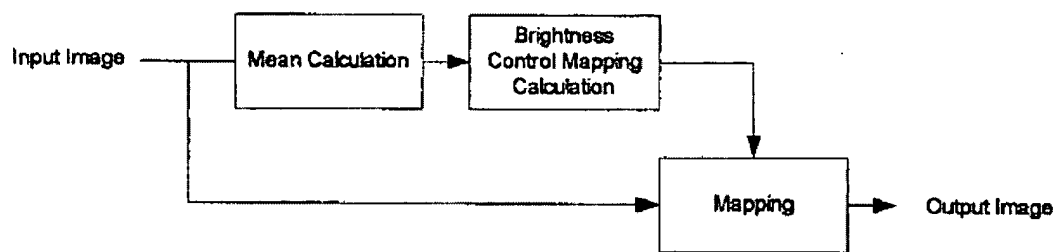
Method and apparatus for brightness control with bin underflow and bin overflow

## BACKGROUND OF THE INVENTION

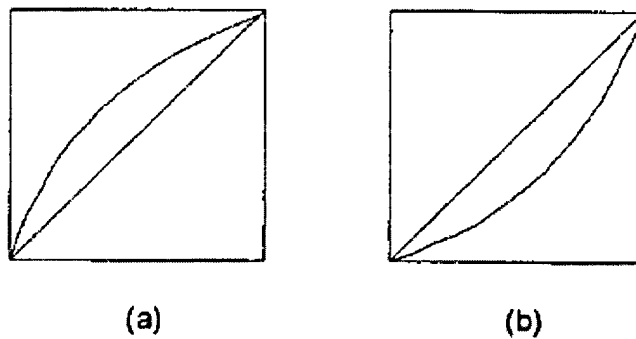
The present invention relates to an apparatus for improving picture quality by varying average brightness of image signals, and a method thereof.

## DESCRIPTION OF THE RELATED ART

### 1. Drawings of related art



<FIG. 1> Schematic of automatic gain control



<FIG. 2> Example of mapping on automatic gain control

### 2. Construction of related art

An automatic gain control method has the construction of a mean calculation

unit, a brightness control mapping calculation unit and a mapping unit.

### 3. Operation of related art

The mean calculation unit estimates an average brightness of input image.

The brightness control mapping calculation unit constructs the mapping for use in accordance with the average brightness. When the average brightness is dark, the mapping above  $g[k]=k$  is used, and when the average brightness is bright, the mapping lower than  $g[k]=k$  is used.

The mapping unit applies the constructed mapping to the input image.

### 4. Problems of the related art

## SUMMARY OF THE INVENTION

Contents of the paper (by order)

#### 1-1. Invention related to circuits

Circuit diagram: to show with block diagram (including neighboring function blocks)

Detailed circuit diagram: to show with detailed circuit diagram including the new function block(s), which is the key feature of the present invention.

Waveforms or flowcharts: to include waveforms if possible. Flowchart is a must for the microcomputer.

#### 1-2. Apparatus-related invention

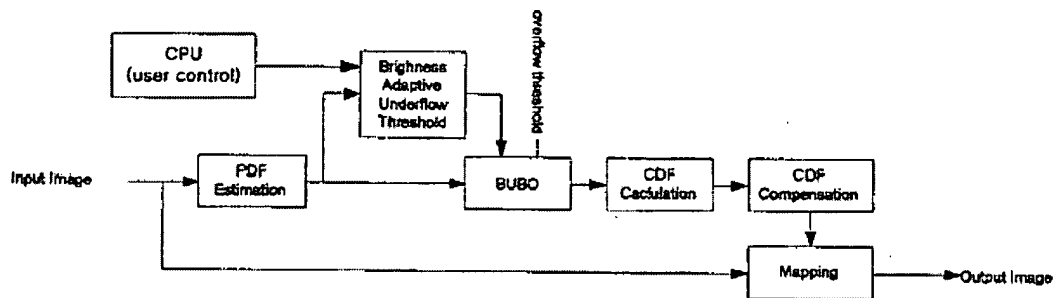
Drawings: to show the overall structure of the invention with perspective view

Detailed drawings: to show the detailed parts of the invention with exploded perspective views and sectional views

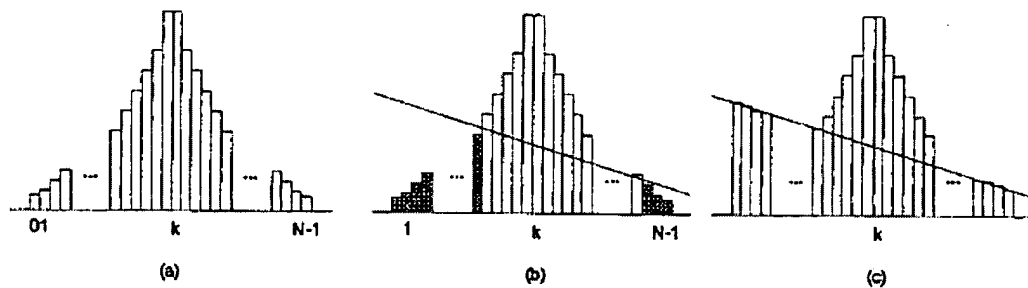
Drawings of operation: if necessary, to show each operation of the invention.

2. Object: technical effect aimed by the present invention  
e.g.) The present invention is suggested to achieve ....., by performing .....
3. Construction: to list constituents elements of the invention
4. Operation: to describe in detail the interoperation among the respective elements
5. Effect: to describe technical advantages that solve the problems of the conventional art, for example, in view of new function, economical efficiency, etc., with accompanying data or drawings showing the actual effects obtained when being applied to the existing product.
6. Please insert more pages when the description exceeds one page.

Drawing of the invention

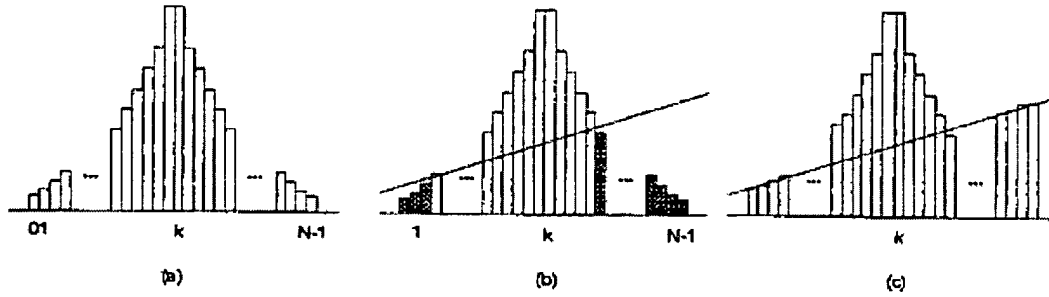


<FIG. 3> Brightness control with bin underflow bin overflow



<FIG. 4> Bin underflow for brightness increase, (a) input pdf, (b) bin underflow occurs,

and (c) pdf after bin underflow



<FIG. 5> Bin overflow for brightness decrease, (a) input pdf, (b) bin overflow occurs, and (c) pdf after bin overflow

## 2. Object of the present invention

The present invention aims to improve the picture quality by varying average brightness in contrast enhancement without using other external resources.

## 3. Construction of the present invention

The present invention employs the construction having a pdf estimation unit, a brightness adaptive underflow threshold calculation unit, a bin underflow bin overflow (BUBO) unit, a cdf calculation unit, a cdf compensation unit and a mapping unit.

## 4. The operation of the present invention

The pdf estimation unit estimates pdf from the input image. For example, the pdf estimation unit may obtain pdf of the input image by using the mathematical formula as follows:

$$(\text{Formular}) \text{pdf}[f(i,j)] = 1, \text{ for } \forall (i,j) \in I$$

$f(i,j)$  : (i, j)th pixel value

I: index set

p[k]: probability that  $f(i, j) = k$

The brightness adaptive underflow threshold calculation unit analyzes an average brightness of a given image. If the average brightness is dark, the brightness adaptive underflow threshold calculation unit outputs a decreasing function as an underflow threshold, and if the average brightness is bright, outputs an increasing function as an underflow threshold. The brightness adaptive underflow threshold calculation unit may output underflow threshold based on the setting values by the user control, instead of analyzing the average brightness of the given image. For example, the underflow threshold may be used with the following formula:

(Formula)  $th\_u[k] = a * (k - k\_0) + b$ ,

$a < 0$ , for brightness  $< th\_m$

$a > 0$ , for brightness  $> th\_m$

b : constant

$k\_0$  : constant

With the underflow threshold and overflow threshold as given, the BUBO unit detects the bin underflow and bin overflow,

(Formula) if  $pdf[k] < th\_u[k]$ , then bin underflow,

if  $pdf[k] > th\_o[k]$ , then bin overflow

and accordingly adjusts the pdf,

(Formula)  $pdf[k] = th\_u[k]$ , if bin underflow,

$pdf[k] = th\_o[k]$ , if bin overflow,

$pdf[k] = pdf[k]$ , otherwise.

The cdf calculation unit obtains cdf through the cumulative sum of pdf.

$$\text{(Formula) } cdf[k] = \sum_{t=0}^k pdf[t]$$

The cdf compensation unit compensates for the influence on the cdf by the BUBO unit. For example, the compensation can be made by,

$$\text{(Formula) } cdf[k] = (cdf[k] = cdf[N-1]/(N-1)) + k$$

or

$$\text{(Formula) } cdf[k] = (N-1)/cdf[N-1] * cdf[k].$$

The mapping unit varies pixel value of the input image using the cdf as the mapping function.

$$\text{(Formula) } g(i,j) = cdf[f(i, j)]$$

## 5. Effect of the present invention

The present invention can improve the picture quality without using external resources in contrast enhancement, by varying the average brightness of the image signals.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of automatic gain control,

FIG. 2 shows an example of mapping used for the automatic gain control,

FIG. 3 shows the automatic brightness control with bin underflow bin overflow,

FIG. 4 shows the bin underflow for brightness increase, wherein (a) shows the input pdf, (b) shows the bin underflow occurrence, and (c) shows the pdf after bin underflow, and

FIG. 5 shows the bin overflow for brightness decrease, wherein (a) shows the

input pdf, (b) shows the bin overflow occurrence, and (c) shows the pdf after bin overflow.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Algorithm for image enhancement with bin-underflow and bin-overflow

- Jae-Hwan Oh, Seung-Joon Yang, Young-Jun Park and Hyun Kang

# Algorithm for Image Enhancement with Bin-Underflow and Bin-Overflow

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## Abstract

Despite the numerous studies that have been pursued heretofore, a contrast enhancement algorithm, i.e., one of the signal processing algorithms for image enhancement, was hard to apply to the motion picture field such as TVs, due to screen flickering and difficulty in realizing dynamic range of the adjustable contrast level.

In this paper, we suggest an efficient algorithm using bin-underflow bin-overflow (BUBO), which enables smooth adjustment in contrast level and which does not causes any side-effect such as flickering. We also intend to suggest a black/white level stretch algorithm which achieves enhancement in grayscales of dark portion and bright portion of the image, together with an algorithm for adjusting brightness of the screen with a static dynamic range.

## I. INTRODUCTION

The contrast enhancement algorithm has its goal on widening dynamic range of the grayscale level and enhancing the image contrast. As is frequently shown in underexposed or overexposed photographic images, inappropriate contrast may result in substantial degradation in image quality. The histogram equalization (HE) [1]-[2] is one of the algorithms that are generally used to improve image contrast. To increase the contrast, 'HE' causes values of the picture element (pixel) of the image to have uniform distribution and thus to use all the available area of the grayscale level. 'HE' is especially efficient in the dark area having minute details. However, because the cumulative distribution function (cdf) generated in accordance with the histogram of the pixels is directly applied as the mapping function, adjusting the contrast level is difficult, and image quality may even degrade if the image has excellent quality already.

A convexoconcave function[3] algorithm, which obtains average of the probability density function (pdf) of the image, determines areas with respect to the grayscales and calculates transfer function in accordance with the pdf distribution in each area, may enhance the contrast even in the local area in accordance with the determined areas. However, if applied to the motion picture image instead of still images, flickering may occur due to the average which changes with the varying pdf. Accordingly, contrast may not be applied effectively, which means that additional algorithms are needed for the special patterns such as monotonic images.

In the present paper, an effective algorithm using bin-underflow bin-overflow (BUBO) is suggested. With this algorithm, brightness mapping function can be calculated efficiently even when the histogram of the image is particularly focused to a



certain brightness level of the image and also the flickering is minimized, so that the maximum contrast effect is guaranteed. Further, by using threshold of two concepts for use in the BUBO contrast enhancement algorithm, level in the black/white area can be stretched with adjustment of image brightness and without reduction in dynamic range of the brightness.

Simulation of the present algorithm proved that flickering rarely occurs in the still image and also in the video sequence. Also, contrast was enhanced greatly, while the contrast level can be adjusted smoothly. Furthermore, brighter and clearer picture quality was obtained through the brightness control and the black/white level stretch. As the algorithm is realized by not only the software but also the hardware, performance becomes more effective, and construction becomes efficient especially in view of cost.

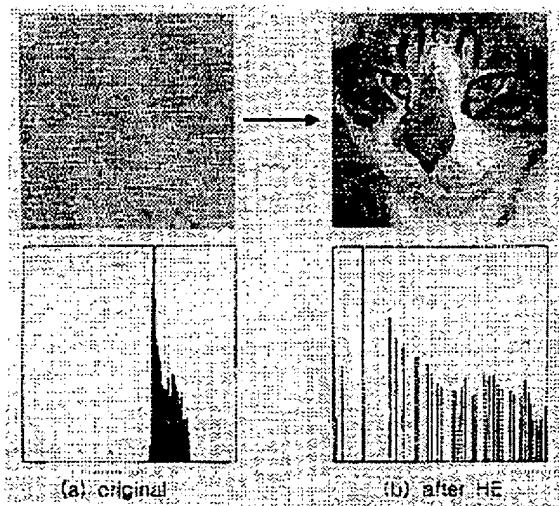
Contents of this paper are arranged in the following order. Chapter II describes existing algorithms for contrast enhancement and analyses the problems accompanying the existing algorithms. Chapter III describes the suggested contrast enhancement algorithm using the BUBO, the brightness control method using thresholds of two concepts for use in the suggested algorithm, and the black/white level stretch method. Chapter IV analyses performances obtained by the suggested methods through several tests, and finally, Chapter V concludes the description.

## II. Existing algorithms

In this section, several existing algorithms for contrast enhancement of the image will be introduced with brief description of their advantages and disadvantages.

### A. Histogram Equalization (HE)

Many methods have been suggested for the enhancement of image contrast. Particularly, due to excellent effect and simplicity, 'HE (Histogram Equalization)' became a renowned one among the image contrast enhancement methods, with lots of applications [4]-[7]. The main object of the 'HE' is to give uniform distribution of image histogram and thus rearrange the distribution of brightness values. In other words, the 'HE' obtains histogram value or pdf through the counting of the brightness level from the input image and then obtains cdf from the obtained values. Using the cdf as obtained, the histogram of the given image is changed to uniform pattern, and thus the contrast of the image improves. FIG. 1 shows one example of the 'HE'.



<FIG. 1> One example of Histogram Equalization

However, shortcoming of the 'HE' is that it is hard to adjust the degree of contrast enhancement. As soon as the image is given, pdf and cdf are obtained, and the pdf and cdf as obtained are used as the mapping for the contrast enhancement. However, with the image of peculiar characteristics or with the image degraded with noise, undesirable result may be caused. Further, the 'HE' does not guarantee static relative

brightness. The brightness of the image, which is obtained through the 'HE', is not related with the brightness of the given image, and therefore, if applied to the video sequence, there is no boundary between the bright scene and dark scene. The 'HE' can be quite effective in the dark region having details. However, the image of superior quality may be degraded with the 'HE'. Accordingly, a rather complex algorithm is needed to overcome such shortcoming, which is quite difficult to realize.

#### B. Convexoconcave Function

The convexoconcave function obtains pdf and cdf using the histogram of the input image, calculates mean brightness from the pdf and cdf as obtained, and fixes the means brightness of the image by fixing the outputs related to the mean brightness. Further, the histogram of the image is divided into plural regions based on the calculated mean brightness, cdf for each region is obtained, and transfer function is obtained in accordance with the density of the cdf. That is, the convexoconcave function has a mechanism of increasing contrast of the overall image, in which the transfer function has a steep sloping degree in the brightness level region where the pixel distribution is particularly focused, while the transfer function has a rather smooth sloping degree in the region having sparse pixel distribution. FIG. 2 shows one example of transfer function, which is obtained through the above process.

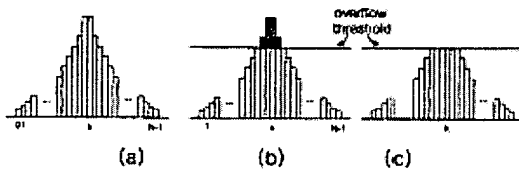


In this section, three algorithms, that is, the contrast enhancement, brightness control and black/white level stretch using the BUBO, will be described and main characteristics thereof will be explained.

#### A. Contrast Enhancement with Bin-Underflow and Bin-Overflow

As mentioned above, the 'HE' sometimes degrades image quality due to mapping functions calculated from the overly populated area where the pdf is abnormally collected. That is, if the pdf is excessively distributed in the dark region of the grayscale level, the cdf line abruptly rises from the dark area, forming an unnatural curve of the mapping function.

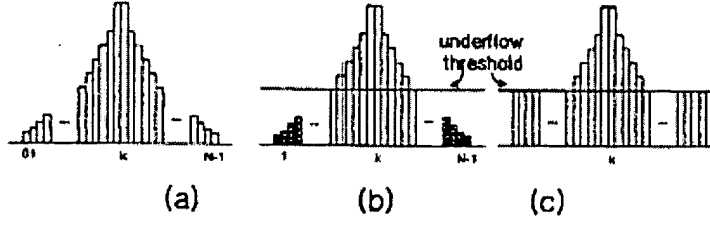
The contrast enhancement algorithm using BUBO can overcome such shortcomings of the 'HE', through the use of two concepts of overflow threshold and underflow threshold. That is, when the pdf of the image is overly collected in certain grayscale level, the overflow threshold serves as the clipping for the pdf that exceeds the overflow threshold so as to prevent subsequent abrupt increase of the cdf. FIG. 3 shows one example of how the overflow threshold is applied.



<FIG. 3> Bin overflow operation, (a) input pdf, (b) bin overflow occurs, and (c) pdf after bin overflow

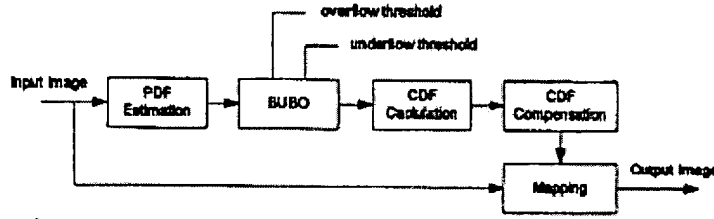
If there is no pdf in image or if there is a grayscale level having the pdf lower than the underflow threshold, the underflow threshold is used as a replacement for the pdf as much as the underflow threshold, in compensation for the shortage of cdf

increase. FIG. 4 shows this process using the underflow threshold.



<FIG. 4> Bin underflow operation, (a) input pdf, (b) bin underflow occurs, and (c) pdf after bin underflow

A contrast enhancement algorithm using the two concepts of overflow threshold and underflow threshold can be constructed as follows:



<FIG. 5> Contrast enhancement with Bin-underflow Bin-overflow

In FIG. 5, pdf is estimated first, by calculating the histogram of the input image. For example, the pdf of the input image can be obtained by using the following formula:

<Formula 1>

$$\text{pdf}[f(i,j)] \neq 1, \text{ for } \forall(i,j) \in I$$

$f(i,j)$  : (i,j)th pixel value

$I$  : index set

$P[k]$  : probability that  $f(i,j) = k$

Next, bin underflow and bin overflow are detected by using the underflow threshold and overflow threshold, respectively, and the pdf is adjusted by the following formula:

<Formula 2>

$pdf[k] = th_o$ , if bin overflow,

$pdf[k] = th_u$ , if bin underflow,

$pdf[k] = pdf[k]$ , otherwise

Accordingly, when bin overflow occurs due to accumulation of the histogram, overflow threshold is substituted for the pdf of the grayscale level, and when the resultant value of the accumulation of the histogram does not reach the underflow threshold, the pdf of the corresponding grayscale level is substituted for the underflow threshold. By doing so, initial pdf of the input image is changed to a new pdf according to the BUBO algorithm.

By using the pdf adjusted as described above, the cdf is obtained through the cumulative sum of pdf.

<Formula 3>

$$cdf[k] = \sum_{t=0}^k pdf[t]$$

t: 0~k

Due to the influence of the overflow threshold and underflow threshold, the maximum cumulative sum of the obtained cdf may not reach, or exceed the pixel value of the input image. Accordingly, the influence of the BUBO algorithm over the cdf needs compensation. For example, compensation can be made by

<Formula 4>

$$cdf[k] = (cdf[k] - cdf[N-1] * k / (N-1)) + k$$

or

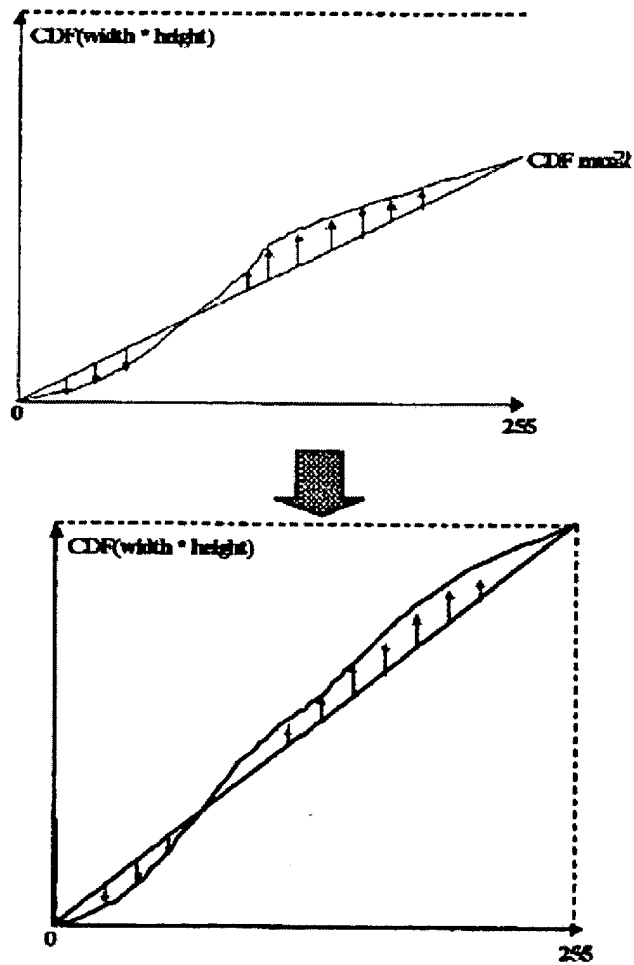
<Formula 5>

$$cdf[k] = (N-1) / cdf[N-1] * cdf[k]$$

In the case of <Formula 4>, cdf curve is compensated by calculating a difference between the cdf curve of pdf accumulation and a straight line connecting the maximum cdf and origin point, and then adding the calculated difference to the original straight line. In the case of <Formula 5>, compensation effect can be obtained by normalizing the cdf curve into the range of grayscale. However, if applied to the hardware level, the <Formula 5> becomes complex due to increase in undecided denominator of the division, and therefore, cost increases.

FIG. 6 shows the calculation of transfer function by compensating the cdf using the <Formula 4>. As shown in FIG. 6, the number of pdf being clipped by the overflow threshold is greater than the number of pdf being filled by the underflow threshold. If things are opposite, that is, if the number of pdf being filled by the underflow threshold is greater than the number of pdf being clipped by the overflow threshold, the maximum cdf becomes larger than the number of entire pixels of the input image. However, this is not a big problem as the cdf curve can be recovered to the normal scale range due to the compensation process in which a difference between the cdf curve and the line connecting the maximum cdf and the origin point is obtained and added to the original straight line.





<FIG. 6> cdf compensation

The cdf calculated as shown in FIG. 6 is normalized to 0~255 grayscale level, and by using this with transfer function, the pixel value of the input image is converted by the following formula:

<Formula 6>

$$g(i, j) = \text{cdf}[f(i, j)]$$

By using the thresholds of two concepts, the contrast enhancement algorithm using BUBO can properly deal with the image statistics, and adjust the contrast level in accordance with the setting of the thresholds. Further, by setting the underflow

threshold and overflow threshold properly, another effect of performing ‘HE’, which is the most-generally used algorithm, can also be obtained.

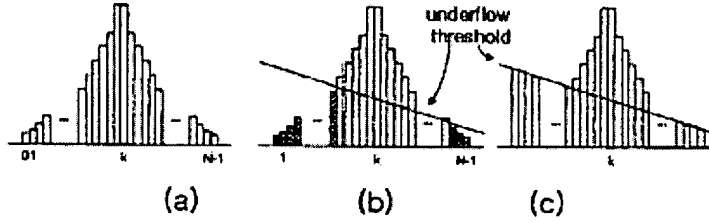
As described above, the BUBO algorithm improves the shortcoming of the ‘HE’ of having inaccurate calculation of the transfer function due to abnormal increase of cdf by the pdf, and also maintains the advantage of the ‘HE’, i.e., the simplicity. Furthermore, due to its extendibility, which means that the threshold used in the BUBO can be applied to the brightness control and black/white level stretch algorithms which will be described in detail in later part of this paper, it can be quite cost-effective when applied to the hardware level.

#### B. Brightness control with bin-underflow and bin-overflow

In designing the algorithm for image processing, a need arises to increase or decrease the brightness of the image in accordance with the characteristics of the application to be used. And usually, the brightness is adjusted either by using addition/reduction of offset in accordance with the brightness of the image, or by adding auto gain control (AGC) circuit. In the former case, image saturation occurs in the direction of black level or white level due to the offset addition or reduction and thus causes loss of dynamic range of the grayscale level. In the latter’s case, complexity increases due to addition of circuit, and therefore, cost increases.

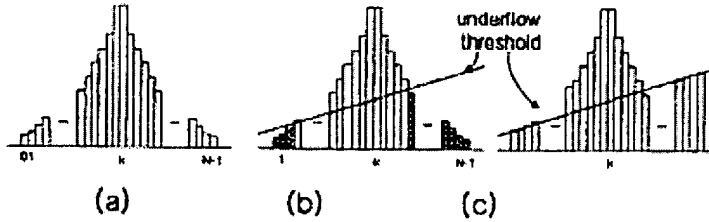
The brightness control algorithm using the BUBO can be realized to the same simplicity and without a loss of dynamic range of the grayscale level, by simply applying a sloping degree of the function to the overflow threshold and underflow threshold described above. In other words, by applying the negative slope as the underflow threshold, the dark level of the grayscale level can be replaced by a

underflow threshold larger than the bright level, and therefore, the curve of the transfer function can increase while maintaining the dynamic range of the grayscale. FIG. 7 illustrates how the brightness increases when the negative slope is applied as the underflow threshold.



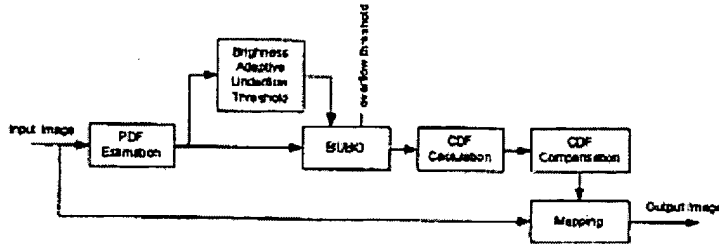
<FIG. 7> Bin underflow for brightness increase, (a) input pdf, (b) bin underflow occurs, and (c) pdf after bin underflow

If a positive slope is applied as the underflow threshold, then the bright level of the grayscale is substituted by a underflow threshold larger than the dark level, and therefore, the curve of the transfer function decreases. FIG. 8 shows how the brightness decreases when the positive slope is applied as the underflow threshold.



<FIG. 8> Bin underflow for brightness decrease, (a) input pdf, (b) bin underflow occurs, and (c) pdf after bin underflow

FIG. 9 shows the construction of brightness control algorithm using BUBO.



<FIG. 9> Brightness control using bin-underflow bin-overflow

In FIG. 9, pdf is estimated from the input image first. Next, an average brightness is analyzed from the estimated result. If the average brightness is dark, a decrease function outputted as the underflow threshold, and if the average brightness is bright, the increase function is outputted as the underflow threshold, adaptively. Alternatively, the underflow threshold may be outputted based on the setting value by the user control instead of analyzing the average brightness of the image.

<Formula 7>

$$th\_u[k] = a * (k - k\_0) + b,$$

$$a < 0, \text{ for brightness} < th\_m$$

$$a > 0, \text{ for brightness} > th\_m$$

b: constant

$k\_0$  : constant

Applying sloping degree to the overflow threshold can influence the pdf increase pattern of the grayscale level. For example, if the positive sloping degree is applied as the overflow threshold, the cdf increase in the dark area increases, while the cdf increase in the bright area decreases. In other words, contrast in dark area increases compared to the bright area, and this becomes a critical factor that determines contrast

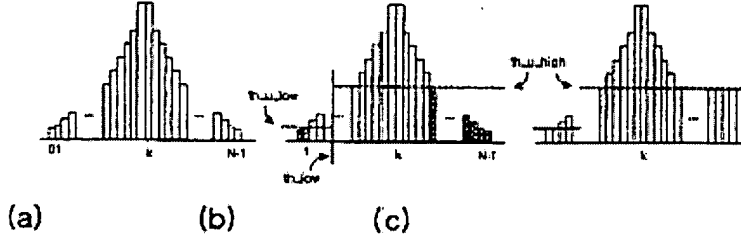
level.

The brightness control using BUBO can be effectively applied to the brightness setting in accordance with the characteristics of the panel such as LCD (Liquid Crystal Display).

#### C. Black and white level stretch with bin-underflow and bin-overflow

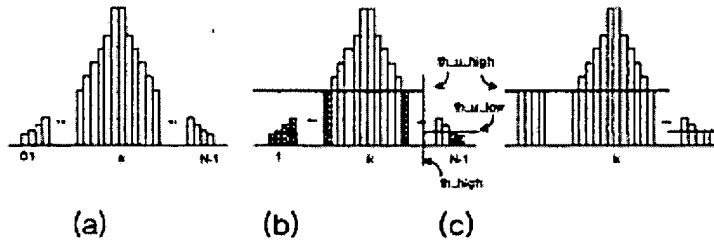
Due to the nature of human eyes in perceiving things, black white levels play a crucial role in the improvement of image quality. Even the same image or motion picture can be perceived with various levels of clarity to the viewer's eyes, depending on the black white levels. Accordingly, many attempts have been made to realize the image of excellent clarity by applying additional black/white level stretch algorithm to the contrast enhancement algorithm, however, problems such as increased complexity and costs also followed.

The black/white level stretch algorithm using BUBO can be realized simply by setting independent overflow threshold and underflow threshold for the black range and white range of the grayscale level for stretching. That is, the underflow threshold of the black range is set to be low, and the value substituted by the underflow threshold becomes low, and therefore, the increase in cdf decreases. By performing the cdf compensation as the above, the level of the desired black range is stretched. In this case, if '0' is used as the underflow threshold of the black range for stretching, pdf of the input image can be used without any change, and if the overflow threshold is big enough, the effect of histogram equalization can be obtained in the same area.



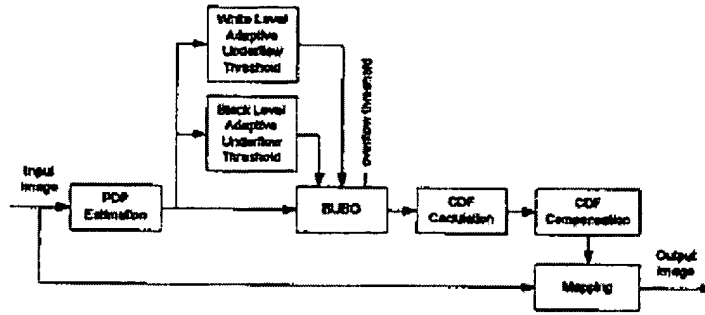
<FIG. 10> Bin underflow for black level stretch, (a) input pdf, (b) bin underflow occurs, and (c) pdf after bin underflow

Referring to FIG. 11, the underflow threshold of the white range for stretching is set to be low, and the value substituted by the underflow threshold becomes low, and therefore, the increase in cdf decreases. By performing the cdf compensation as the above, the level of the desired white range is stretched. In this case, if '0' is used as the underflow threshold of the white range for stretching, pdf of the input image can be used without any change, and if the overflow threshold is big enough, the effect of histogram equalization can be obtained in the same area.



<FIG. 11> Bin underflow for white level stretch, (a) input pdf, (b) bin overflow occurs, and (c) pdf after bin overflow

One example of black/white level stretch algorithm using BUBO is shown in FIG. 12.



<FIG. 12> Black/white level stretch using bin-underflow bin-overflow

In FIG. 12, pdf is estimated from the input image first. If the grayscale expressing the dark area of the given image is high, the underflow threshold, which is lower than the underflow threshold being applied to the other ranges, is outputted with respect to the grayscale range for stretching. For example, the underflow threshold can be used as the following:

<Formula 8>

$$th\_u[k] = th\_u\_low, \text{ for } k < th\_low$$

$$th\_u[k] = th\_u\_high, \text{ for } k \geq th\_low,$$

where

$$th\_u\_low < th\_u\_high$$

A better black stretch effect can also be obtained by outputting an overflow threshold, which is lower than the overflow threshold being applied to the other ranges, with respect to the grayscale range for stretching. That is, when the BUBO algorithm is applied to the image such as letter box, if the black level occupying relatively large area of the image is converted to one brightness level, the same will be clipped by the overflow threshold and thus, it does not cause any problem. However, if the black level is converged over the large black range due to the presence of noise, increase pattern of cdf becomes uncontrollable. In this case, the brightness corresponding to the black of

the letter box can be stretched clearly without having to use additional algorithms, by setting the independent overflow threshold at a low value with respect to the black range for stretching.

For the stretching of white level, when the grayscale expressing the bright portion of the given image is low, the underflow threshold, which is lower than the underflow threshold for applying to the other ranges, is outputted with respect to the grayscale range for stretching. For example, the underflow threshold can be used as the following formula:

<Formula 9>

$$th\_u[k] = th\_u\_high, \text{ for } k < th\_high$$
$$th\_u[k] = th\_u\_low, \text{ for } k \geq th\_high,$$

where

$$th\_u\_low < th\_u\_high$$

In this case, a better white stretching effect can be obtained by outputting an overflow threshold, which is lower than the overflow threshold for applying to the other ranges, with respect to the grayscale range for stretching.

That is, by applying black/white level stretch algorithm to the image properly, the dark area becomes darker and the bright area becomes brighter, and as a result, more vivid visual effect is obtained.

#### IV. Tests and results

Image tests have been conducted with respect to three algorithms, i.e., contrast enhancement algorithm, black/white level stretch algorithm and brightness control algorithm to evaluate the performance of the suggested algorithms, and in this section,



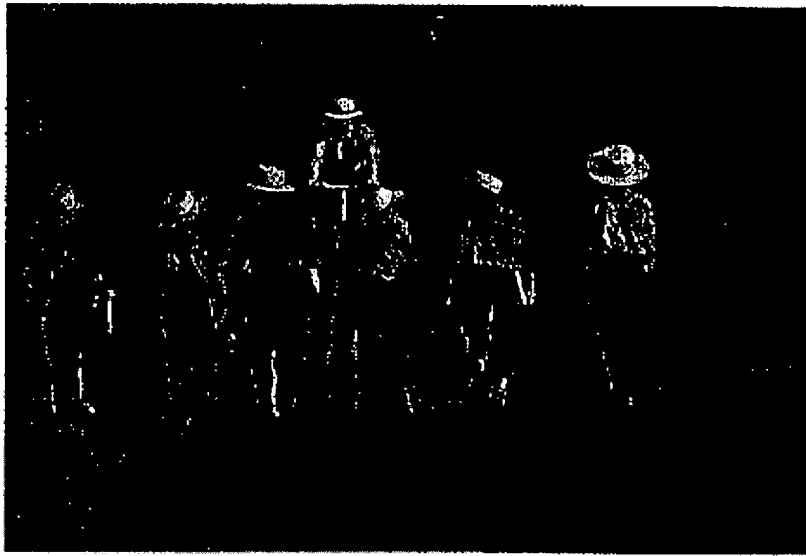
the tests and their results will be described. For the image test, the BUBO algorithm was realized in the hardware level, and more than 1000 still images of the image database were subject to the image tests. Additionally, high quality source such as DVD and various types of motion picture sources such as RF broadcast were also used as the part of the test, and in this paper, one result will be described as an example.

The result of image test using BUBO algorithm was performed with respect to only the right half of the image so as to enable comparison easier, and a curve of the transfer function, which is generated by the BUBO algorithm, is shown. Additionally, the shape of pdf changed by the BUBO algorithm is illustrated with the pdf before the change to enable more convenient comparison.

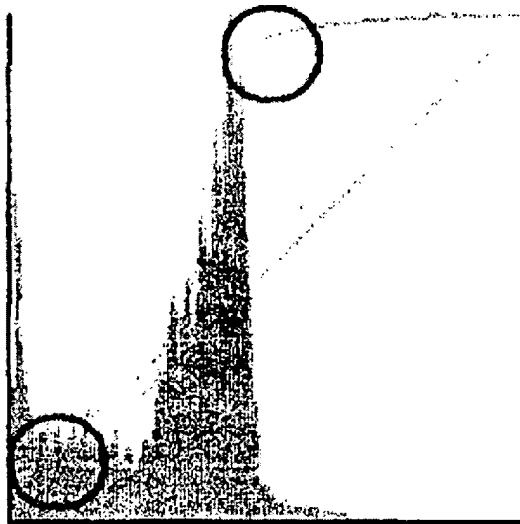
A block diagram realized in hardware level is also attached to this paper, to illustrate the image enhancement result of the BUBO.

#### A. Contrast enhancement with bin-underflow and bin-overflow

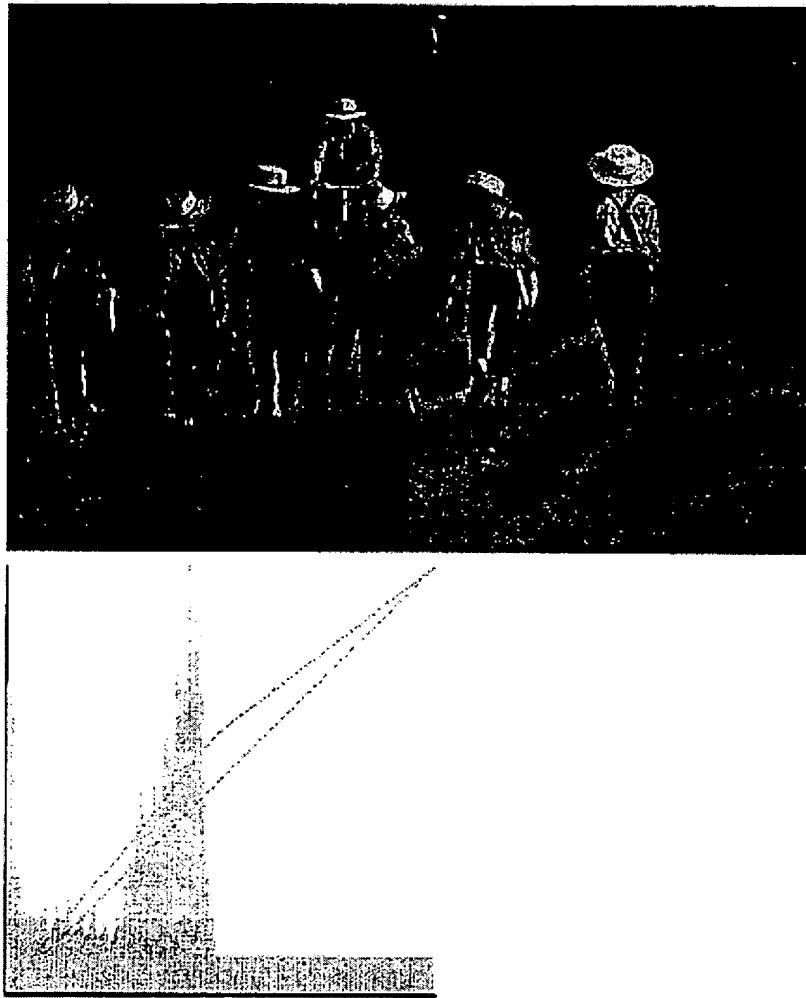
In compensating the cdf, the contrast enhancement using BUBO algorithm adopted the formula 4. FIG. 13 shows one example in which the BUBO algorithm is applied to one still image.



(a) original image



(b) histogram equalized image



(c) contrast enhanced image with BUBO

<FIG. 13> Contrast enhancement with BUBO

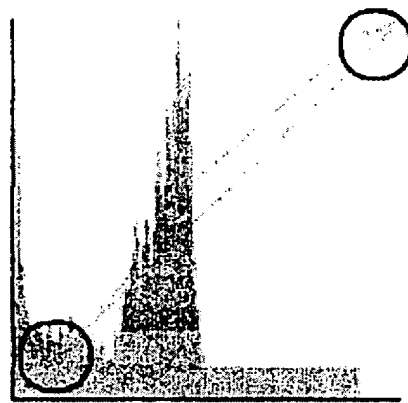
FIG. 13(b) shows the result of histogram equalization with respect to the entire screen, which is compared to the case where the BUBO algorithm is used. As shown, the histogram equalization may even drop the image quality due to the mapping function calculated from the pdf when the pdf is excessively collected at a certain portion. More specifically, pdf is excessively populated in the dark area among the grayscale level, resulting in abrupt increase of the cdf curve in the dark area and subsequent deformation of the curve of the mapping function. In the area corresponding

to the intermediate level of the grayscale also shows the saturation of the cdf curve, again, due to the abnormal focusing of the pdf in this area. FIG. 13(c) shows the image which is enhanced by the use of BUBO. As shown, excessive pdf in the grayscale is clipped by the overflow threshold, and therefore, abnormal increase of cdf is controlled. Also, the pdf shortage in the bright area of the grayscale is substituted by the underflow threshold, and thus helps the constant increase of cdf curve.

In short, with the contrast enhancement algorithm using BUBO, it can be said that only the increase/decrease pattern of pdf of the image is taken and applied to the mapping function. By doing so, excessive emphasis with respect to a certain grayscale level is controlled, and as a result, the effect of getting balanced contrast enhancement can be obtained.

#### B. Black and white level stretch with bin-underflow and bin-overflow

The black/white level stretching using the BUBO algorithm applies independent overflow threshold and underflow threshold to the black range for stretching so as to obtain the effect of contrast enhancement. Referring to FIG. 14, the black range is referred to by 32, and the white range is referred to by 230. Also, the underflow threshold is set to '0'.



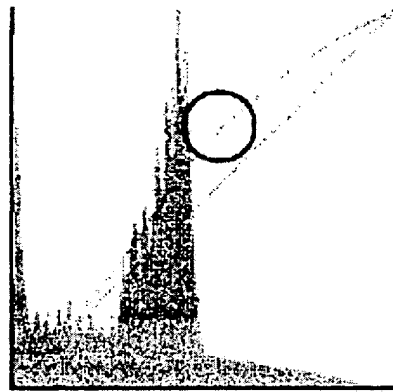
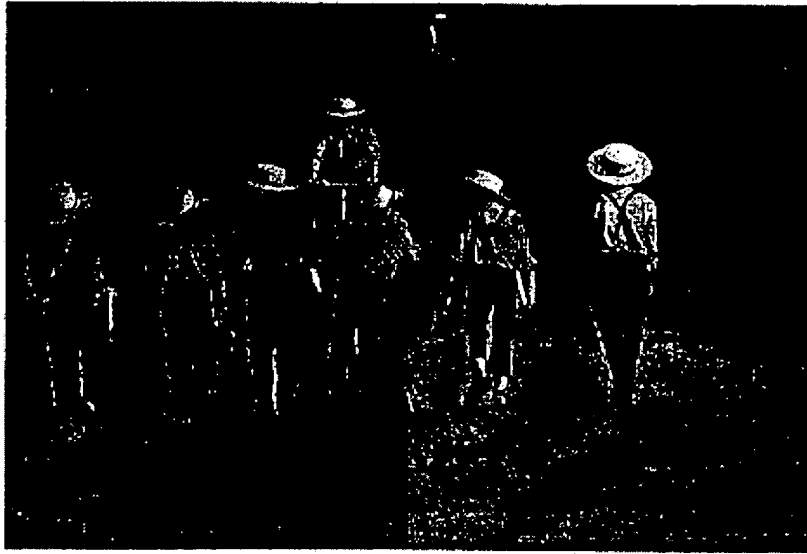
<FIG. 14> Black/white level stretched image with BUBO

Referring to FIG. 14, the overflow threshold, which is same as the underflow threshold of the other ranges, is given to the black range and white range. By doing so, two effects can be obtained. That is, a certain pdf is not filled with the underflow threshold, but instead, the pdf of the input image itself is used. Secondly, excessive focusing of pdf and subsequent increase of cdf can be prevented by the overflow threshold. The image test result shows that the level of the black and white ranges are stretched, and the black range of the transfer function is lowered while the white range of the transfer function is raised. In short, with the contrast enhancement using the

BUBO, it may feel like the overall image becomes a little bit darker, however, it is easily noticeable that the image becomes clearer too.

### C. Brightness control with bin-underflow and bin-overflow

The brightness control algorithm using BUBO algorithm is realized by applying a sloping degree to the underflow threshold in the grayscale area excluding the area for black/white level stretching. One thing to make sure is that there has to be a limitation so that the value by the sloping degree of the underflow threshold may not exceed the overflow threshold. By doing so, malfunction due to the inverse between the overflow threshold and the underflow threshold can be avoided. FIG. 15 shows one example in which a negative sloping degree is applied for the underflow threshold to increase the brightness.



<FIG. 15> Brightness increased image with BUBO

As shown, by applying the function having negative sloping degree to the underflow threshold, the amount of pdf accumulated in the dark area increases, and the entire cdf curve is raised so that the transfer function curve becomes point-headed. In other words, the overall mapping function can be increased without reducing the dynamic range of the grayscale, and as a result, the brightness is increased.

## V. Conclusion

We suggested algorithms that could enhance image contrast, adjust the



brightness in accordance with the application type or the panel characteristics, and stretch the black/white level, through the use of the bin-underflow bin-overflow (BUBO).

In particular, as is proven through the tests in the hardware level, the contrast enhancement algorithm using the BUBO can control the flickering phenomenon, which is one of the abnormalities that occur due to abrupt change in pdf between the application in the still image and application in the motion picture such as video sequence, and contrast effect can be applied with higher efficiency.

Furthermore, clearer image representation can also be obtained in the monotonic image such as letter-box without having to use additional algorithm such as pattern detection algorithm, by applying the black/white level stretch algorithm with BUBO.

When applied to the monitor such as LCD, the brightness control algorithm using BUBO enables clear representation of the image without causing saturation in any area, and with maintaining the dynamic range of the grayscale.

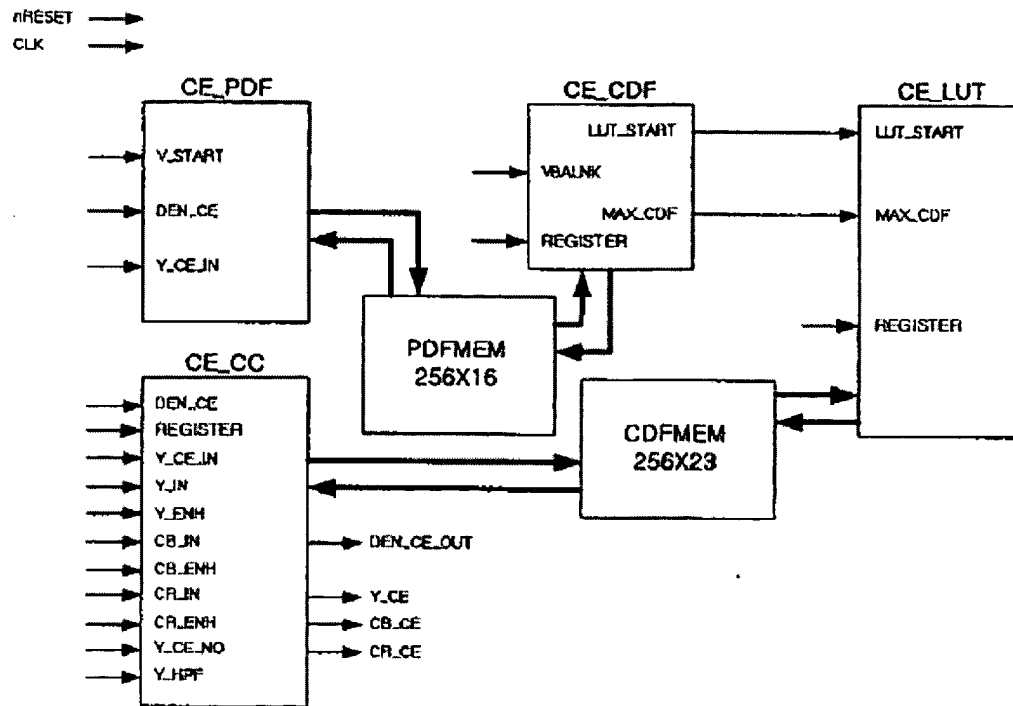
The BUBO algorithm realizes all the functions of contrast enhancement, black/white level stretch and brightness control using the thresholds of two concepts, and therefore, it is quite simple compared to the effect it can provide. Accordingly, the hardware design in minimum extent can provide the maximum effect.

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Attachment: Hardware design/realization of image enhancement algorithm with BUBO



WHAT IS CLAIMED IS:

1. An image enhancement method and apparatus comprising a pdf estimation unit, a brightness adaptive underflow threshold calculation unit, a bin underflow bin overflow (BUBO) unit, a cdf calculation unit, a cdf compensation unit and a mapping unit.

2. An image enhancement method and apparatus of claim 1, comprising a pdf estimation unit for estimating a pdf from an input image.

3. An image enhancement method and apparatus of claim 1, comprising a pdf estimation unit for estimation a pdf of the input image by using the following formula:

(Formula)  $\text{pdf}[f(i,j)] = 1$ , for  $\forall (i,j) \in I$

$f(i,j)$  : (i,j)th pixel value

$I$  : index set

$P[k]$  : probability that  $f(i, j) = k$

4. An image enhancement method and apparatus of claim 1, comprising a brightness adaptive underflow threshold calculation unit for analyzing an average brightness of a given image, thereby outputting a decreasing function when the average brightness is dark and outputting an increasing function when the average brightness is bright.

5. An image enhancement method and apparatus of claim 4, wherein the brightness adaptive underflow threshold calculation method and apparatus outputs an underflow threshold by the following formula:

(Formula)  $\text{th\_u}[k] = a * (k - k_0) + b$ ,

$a < 0$ , for brightness  $< \text{th\_m}$

$a > 0$ , for brightness  $> \text{th\_m}$

$b$  : constant

$k_0$  : constant

6. An image enhancement method and apparatus of claim 1, comprising a BUBO unit to detect a bin underflow and a bin overflow using a given underflow threshold and a given overflow threshold, and accordingly adjust pdf.

7. An image enhancement method and apparatus of claim 6, wherein the BUBO unit detects the bin underflow and the bin overflow by using the underflow threshold and the overflow threshold with the following formula:

(Formula) if  $pdf[k] < th\_u[k]$ , then bin underflow,  
if  $pdf[k] > th\_o$ , then bin overflow.

8. An image enhancement method and apparatus of claim 6, wherein the BUBO unit adjusts the pdf using the following formula:

(Formula)  $pdf[k] = c[k]$ , if bin underflow,  
 $pdf[k] = const\_o$ , if bin overflow.

9. An image enhancement method and apparatus of claim 6, wherein the BUBO unit adjusts the pdf using the following formula:

(Formula)  $pdf[k] = th\_u[k]$ , if bin underflow,  
 $pdf[k] = th\_o$ , if bin overflow.

10. An image enhancement method and apparatus of claim 1, comprising a cdf calculation unit to obtain a cdf through the cumulative sum of pdf by,

(Formula)  $cdf[k] = \sum_{t=0}^k pdf[t]$

11. An image enhancement method and apparatus of claim 1, comprising a cdf compensation unit to compensate for the influence of the BUBO unit to the cdf.

12. An image enhancement method and apparatus of claim 11, wherein the cdf

compensation unit compensates for the influence of the BUBO unit to the cdf by using the following formula:

$$\text{(Formula) } \text{cdf}[k] = (\text{cdf}[k] - \text{cdf}[N-1]/(N-1)) + k.$$

13. An image enhancement method and apparatus of claim 11, wherein the cdf compensation unit compensates for the influence of the BUBO unit to the cdf by using the following formula:

$$\text{(Formula) } \text{cdf}[k] = (N-1)/\text{cdf}[N-1] * \text{cdf}[k].$$

14. An image enhancement method and apparatus of claim 1, comprising a mapping unit to change the pixel value of an input image by using a mapping function.

15. An image enhancement method and apparatus of claim 14, wherein the pixel value of the input image is changed by using the mapping function and the following formula:

$$\text{(Formula) } g(i, j) = \text{cdf}[f(i, j)].$$

16. An image enhancement method and apparatus, comprising a pdf estimation unit, a user control underflow threshold setting unit, a bin underflow bin overflow (BUBO) unit, a cdf calculation unit, a cdf compensation unit, and a mapping unit.

17. An image enhancement method and apparatus of claim 16, same as recited in claims 2 to 15 (\* Please draft independent claims of claim 16 based on the claims 2 to 15). Please also divide the above independent claims into 'apparatus' claims and

‘method’ claims.